UCRL-JC-124876 Abs

Laser Induced Damage and Fracture in Fused Silica Vacuum Windows

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SPIE Conference on
Laser Induced Damage in Optical Materials
1996 Boulder, Co
October 7-9, 1996

Abstract

Laser induced damage that results in catastrophic fracture has been observed in large (up to 61 cm diameter), fused silica lenses used in high-fluence positions on the Nova and Beamlet lasers. In nearly all cases, damage occurs on the vacuum (tensile) side of the lens. The damage can lead to catastrophic crack growth if the flaw (damage) size exceeds the critical flaw size for SiO_2. If the elastic stored energy in the lens is high enough, the lens will fracture into many pieces resulting in an implosion. The consequences of such an implosion can be severe, particularly for large vacuum systems.

The propagation of laser induced fractures is discussed in terms of a slow-crack-growth model that depends on the size of the initial damage spot, the vacuum environment, the lens or window material, the tensile stress and the duration over which the stress is applied. Both model calculations and experiments are used to describe the details of the crack growth process in these windows. Fracture experiments have been carried out on 15-cm diameter fused silica windows that contain surface flaws caused by laser damage. Fractures that originate at the damage spots are found to propagate in discrete steps producing both a characteristic fracture pattern and glass fragment distribution. Finite element stress calculations of a window before and immediately following fracture have been carried out. The results show that the elastic stored energy is redistributed if the fragments "lock" in place (i.e. bridge the opening). In such cases, the peak stresses at the flaw site can increase leading to further (i.e. secondary) crack growth. If the air leak rate through the fracture (s) is fast enough then the vacuum load is removed before the secondary cracks have sufficient time to propagate. If not, then the secondary fractures will lead to smaller fragments and a vacuum window implosion.

The results of this work have been used to guide the lens and window designs for large vacuum systems used in high power laser applications. Specifically, we will address the issue of the vacuum laser window and lens to be used on the very large target vacuum chamber and vacuum spatial filters of the proposed National Ignition Facility.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.